U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: Population Exposure Analysis

Date: 10/12/2022

AC No: 450.123-1

Initiated By: AST-1

This Advisory Circular (AC) provides guidance and a comprehensive method for performing a population exposure analysis as part of a Flight Safety Analysis (FSA) in accordance with Title 14 of the Code of Federal Regulations (14 CFR) 450.123. In accordance with § 450.123(a), a flight safety analysis must account for the distribution of people across the entire region where there is a significant probability of impact of hazardous debris. In accordance with § 450.123(b), the exposure analysis must (1) characterize the distribution of people both geographically and temporally; (2) account for the distribution of people among structures and vehicle types; (3) use reliable, accurate, and timely source data; and (4) account for vulnerability of people to hazardous debris effects. In its application, an operator must submit a description of the methods used to develop the exposure input data and complete population exposure data, in tabular form, in accordance with § 450.123(c).

The Federal Aviation Administration (FAA) considers this AC an accepted means of compliance for complying with the regulatory requirements of § 450.123. It presents one, but not the only, acceptable means of compliance with the associated regulatory requirements. The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. The document is intended only to provide clarity to the public regarding existing requirements under the law or agency policies.

If you have suggestions for improving this AC, you may use the Advisory Circular Feedback form at the end of this AC.

MICHAEL J O'DONNELL

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1 PURPOSE.

This Advisory Circular (AC) provides guidance and methods for performing a population exposure analysis in accordance with Title 14 of the Code of Federal Regulations (14 CFR) 450.123. This AC is not mandatory and does not constitute a regulation. This AC describes an acceptable means, but not the only means, for performing a population exposure analysis as part of a flight safety analysis.

1.1 Analysis Scope.

An operator's flight safety analysis method must account for all reasonably foreseeable events and failures of safety-critical systems during nominal and non-nominal launch or reentry that could jeopardize public safety, in accordance with § 450.115(a). In accordance with § 450.123(a), a flight safety analysis must account for the distribution of people for the entire region where there is a significant probability of impact of hazardous debris. In § 450.123(a), the standard of "significant" means that the scope of the population exposure analysis is bounded by what is necessary to demonstrate compliance with the risk criteria in § 450.101(a) and (b), consistent with the scope and methods requirements set forth in §§ 450.113 and 450.115.

1.2 Description of Methods.

Section 450.123(c)(1) requires an applicant to submit a description of the methods used in the population exposure analysis, in accordance with § 450.115(c). For a population exposure analysis, physical surveys or other empirical data should be considered benchmark conditions. The results from well-validated high fidelity population models can qualify as a valid benchmark. Section 450.115(c) requires the identification of:

- The scientific principles and statistical methods used;
- All assumptions and their justifications;
- The rationale for the level of fidelity;
- The evidence for validation and verification required by § 450.101(g);
- The extent to which the benchmark conditions are comparable to the foreseeable conditions of the intended operations; and
- The extent to which risk mitigations were accounted for in the analyses.

1.3 Level of Imperatives.

This AC presents one, but not the only, acceptable means of compliance with the associated regulatory requirements. The FAA will consider other means of compliance that an applicant may elect to present. In addition, an operator may tailor the provisions of this AC to meet its unique needs, provided the changes are accepted as a means of compliance by the FAA prior to application acceptance in accordance with § 450.35(a)(1). Throughout this document, the word “must” characterizes statements that directly follow from regulatory text and therefore reflect regulatory mandates. The word “should” describes an option that, if used would constitute a means to comply with the regulation; variation from the provisions of this AC is possible, but must satisfy the regulation to constitute a means of compliance. The word “may” describes variations or alternatives allowed within the accepted means of compliance set forth in this AC.

2 APPLICABILITY.

2.1 The guidance in this AC is for launch and reentry vehicle applicants and operators required to comply with part 450. The guidance in this AC is for those seeking a launch or reentry vehicle operator license, a licensed operator seeking to renew or modify an existing vehicle operator license, and FAA commercial space transportation evaluators.

2.2 The material in this AC is advisory in nature and does not constitute a regulation. This guidance is not legally binding in its own right, and will not be relied upon by the FAA as a separate basis for affirmative enforcement action or other administrative penalty. Conformity with this guidance document (as distinct from existing statutes and regulations) is voluntary only, and nonconformity will not affect rights and obligations under existing statutes and regulations. This AC describes acceptable means, but not the only means, for demonstrating compliance with the applicable regulations.

2.3 The material in this AC does not change or create any additional regulatory requirements, nor does it authorize changes to, or deviations from, existing regulatory requirements.

3 APPLICABLE REGULATIONS AND RELATED DOCUMENTS.

3.1 Applicable United States Code (U.S.C.) Regulation.

- 51 U.S.C. Subtitle V, Chapter 509.

3.2 Related FAA Commercial Space Transportation Regulations.

The following 14 CFR regulations should be accounted for when showing compliance with § 450.123. The full text of these regulations can be downloaded from the U.S. Government Printing Office e-CFR. A paper copy can be ordered from the Government Printing Office, Superintendent of Documents, Attn: New Orders, P.O. Box 371954, Pittsburgh, PA, 15250-7954.

- Section 450.31(a)(6), *General Requirements to Obtain a Vehicle Operator License.*
- Section 450.101, *Safety criteria.*
- Section 450.113, *Flight safety analysis requirements – scope.*
- Section 450.115, *Flight safety analysis methods.*
- Section 450.117, *Trajectory analysis for normal flight.*
- Section 450.119, *Trajectory analysis for malfunction flight.*
- Section 450.121, *Debris analysis.*
- Section 450.135, *Debris risk analysis*.
- Section 450.137, *Far-field overpressure blast effects analysis*.
- Section 450.139, *Toxic hazards for flight.*
- Section 450.187, *Toxic hazards mitigation for ground operations*.

3.3 Related FAA Advisory Circulars.

FAA Advisory Circulars are available through the FAA website, http://www.faa.gov. Some of these are not yet published.

- AC 450.101-1A, *High Consequence Event Analysis,* dated May 20, 2021.
- AC 450.107-1, *Hazard Control Strategies Determination,* dated July 27, 2021.
- AC 450.108-1, *Flight Abort Rule Development*, dated July 27, 2021.
- AC 450.115-1A, *High Fidelity Flight Safety Analysis,* dated June 24, 2021.
- AC 450.115-2, *Medium Fidelity Flight Safety Analysis,* when published.
- AC 450.117-1, *Trajectory Analysis for Normal Flight,* dated August 19, 2021.
- AC 450.119-1, *Trajectory Analysis for Malfunction Flight,* when published.
- AC 450.137-1, *Distance Focusing Overpressure Risk Analysis,* when published.
- AC 450.139-1, *Toxic Risk Hazard Analysis and Mitigations,* when published.

3.4 **Technical Reports Related to Population Exposure Analysis.**

1. Allahdadi, Firooz A., Isabelle Rongier, Tommaso Sgobba, and Paul D. Wilde, *Safety Design for Space Operations*, Sponsored by The International Association for the Advancement of Space Safety, (Watham, MA, Elsevier, 2013).
2. Bureau of Transportation Statistics, "*Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances*," 2021. https://www.bts.gov/content/number-us-aircraft-vehicles-vessels-and-other-conveyances
3. Florida Department of Transportation, "*Statewide Traffic Impacts*", 2020.
4. Larson, Erik, *Large Region Population Sheltering Models for Space Debris Risk Analysis,* American Institute of Aeronautics and Astronautics (AIAA) Atmospheric Flight Mechanics Conference and Exhibit, Report #2005-6322, (San Francisco, CA: AIAA, August 2005).
5. Oak Ridge National Laboratory, "*LandScan, Geographic Information Science and Technology*", 2018. https://landscan.ornl.gov/
6. Range Commanders Council, Risk Committee, Range Safety Group, *Common Risk Criteria for National Test Ranges*, RCC 321-10, (White Sands, NM: RCC, 2010).
7. Socioeconomic Data and Applications Center (SEDAC), "*Gridded Population of the World (GPW)*, v4, CIESIN, (New York, New York: Columbia University, 2020). https://sedac.ciesin.columbia.edu/
8. United States Census Bureau, "*Explore Census Data*", 2020. https://data.census.gov/cedsci/

Note: The industry documents referenced in paragraph 3.4 of this AC refer to the current revisions or regulatory authorities' accepted revisions.

4 DEFINITION OF TERMS.

For this AC, the terms from § 401.7 and the following definitions apply:

4.1 Flight Safety Analysis (FSA)

A quantitative evaluation of the risks to people and critical assets addressing both normal flight and malfunctions of the launch vehicle and safety-critical systems.[1]

4.2 Population Center

A geographic region over which the variation in risk, for each class of individuals, is not significant either because the probability of casualty or the probability density of people is nearly uniform.

4.3 Sheltering

The distribution of people among structures and vehicle types, which affects their vulnerability to hazardous debris.

[1] Under part 450, there are 11 performance-based sections with FSA requirements that fall into three groups. The first group, §§ 450.113 and 450.115, provides requirements on the scope and fidelity of the analyses required by the remaining nine sections. The second group, which consists of five sections from §§ 450.117 through 450.131, specifies the requirements for analyses necessary to develop quantitative input data used by the last four sections. The last group consists of four sections that specify quantitative risk analyses with products necessary to evaluate compliance with the safety criteria in § 450.101. All of the FSA sections must use methods that comply with § 450.101(g) because they are essential to demonstrating compliance with the safety criteria in § 450.101.

5 ACRONYMS.

AC – Advisory Circular

AST – FAA Office of Commercial Space Transportation

CE_C – Conditional Expected Casualties

CFR – Code of Federal Regulations

DFO – Distance Focusing Overpressure

E_C – Collective Risk

FAA – Federal Aviation Administration

FFBO – Far-Field Blast Overpressure

FSA – Flight Safety Analysis

GDP – Gross Domestic Product

GPW – Gridded Population of the World (on-line database)

IIP – Instantaneous Impact Point

km – kilometer

MPL – Maximum Probable Loss

NASA – National Aeronautics and Space Administration

NOP – Neighboring Operations Personnel

PEMB – Pre-Engineered Metal Building

RCC – Range Commanders Council

U.S. – United States

U.S.C. – United States Code

6 FLIGHT SAFETY ANALYSIS.

Launch and reentry flight safety analysis is a process that is inherently dependent on using models and model parameters to simulate the consequences of vehicle failures and the resulting hazardous events, which must account for the distribution of people both geographically and temporally in accordance with § 450.123(b)(1). A population exposure analysis should define a set of scenarios that describe all of the possible distributions of people sufficiently to produce a valid determination of risk using accurate source data from demographic sources, physical surveys, or other methods. The flight hazard area analysis must account for the regions of land, sea, and air potentially exposed to hazardous debris generated during normal flight events and all reasonably foreseeable failure modes, in accordance with § 450.133(a)(1), and all reasonably foreseeable events and failures of safety-critical systems during nominal and non-nominal launch or reentry that could jeopardize public safety, in accordance with § 450.115(a). The population exposure analysis produces input data that is necessary for the flight safety analyses. The population exposure analysis must account for the distribution of people among structures and vehicle types, use reliable, accurate, and timely source data, and account for vulnerability of people to hazardous debris effects in accordance with § 450.123(b)(2) through (b)(4).

Note: In accordance with §§ 450.137, 450.139, and 450.187, a population exposure analysis must also be used to provide input to other public risk analyses to address toxic hazards and far-field overpressure blast effects, if any. Applicants should refer to AC 450.137-1 *Distance Focusing Overpressure (DFO) Risk Analysis*, AC 450.139-1, and *Toxic Release Hazard Analysis* for guidance on those topics.

7 USE OF POPULATION EXPOSURE ANALYSIS IN FLIGHT SAFETY ANALYSIS.

Section 450.123(a) requires the flight safety analysis to account for the distribution of people for the entire region where there is a significant probability of impact of hazardous debris. This requirement is accomplished by performing a population exposure analysis. This analysis results in a quantitative model of the location of people, which varies spatially and accounts for different time periods. The model is often based on data from numerous sources and typically aggregates people into population centers. A population center could be as small as a section of a building or as large as several thousand square kilometers (km).

7.1 Identify Regions of Interest.

As a first step, a population exposure analysis must identify the entire region where there is significant probability of impact of hazardous debris, in accordance with § 450.123(a). The standard of "significant" means that the scope of the population exposure analysis is bounded by what is necessary to demonstrate compliance with the risk criteria in § 450.101(a) and (b), consistent with the scope and methods requirements set in §§ 450.113 and 450.115. The region should consider all types of hazardous debris (as defined in § 401.7), which accounts for hazards from explosive and toxic substances, as well as potential for consequences due to either planned operations (e.g. jettisons) or reasonably foreseeable failures. The extent of the region should always include, at a minimum, the region enclosed by hazardous debris impact points corresponding to flight abort limits (extending with a hazard footprint buffer; see AC 450.108-1). To analyze risks of the failure of a flight abort system (if present) or if there is no active abort system, an operator should identify a region that covers any portion of the Earth where hazardous debris could impact. The extent may be defined by the region where the individual probability of casualty exceeds 1×10^{-14} for individuals in any shelter category.[2] For a suborbital vehicle, the extent may be defined by the region that encompasses the maximum range of the vehicle's worst-case instantaneous impact point (IIP).

7.2 Transit Modes.

The exposure model should also include people in all types of transit vehicles other than aircraft; including ships, boats, autos, buses, trains, and trucks; in accordance with § 450.101(a)(1) and (b)(1). People in aircraft are excluded from the collective risk (E_C) requirements of § 450.101(a)(1) and (b)(1) and people in spacecraft are accounted for by compliance with § 450.169, which discusses launch and reentry collision avoidance. These modes are especially important in areas near the launch/landing site. It is also important to appropriately account for waterborne vessels because the vulnerability of people on waterborne vessels can be quite different than it is on land.

[2] The individual probability of casualty limit comes from the sufficiency to meet the $1E^{-4}$ E_C criteria. $1E^{-14}$ comes from the potential of the entire world (global population) being exposed (such as for random reentry). $1E^{-14}$ is a little smaller than $1E^{-4}$ / Global Population.

7.3 Population Categories.

Section 450.101 contains different safety criteria for people in different categories. One category is "public," meaning, for a particular licensed or permitted launch or reentry, people that are not involved in supporting the launch or reentry. Public includes those people who may be located within the launch or reentry site, such as visitors, individuals providing goods or services not related to launch or reentry processing or flight, and any other operator and its personnel as defined in § 401.7. Public includes a second category "neighboring operations personnel (NOP)" meaning those members of the public located within a launch or reentry site, or an adjacent launch or reentry site, who are not associated with a specific hazardous licensed or permitted operation currently being conducted, but are required to perform safety, security, or critical tasks at the site and are notified of the operation as defined in § 401.7. People that are involved in supporting the launch or reentry do not meet the definition of "public" in § 401.7. The FAA does not have safety oversight of people that are involved in supporting the launch or reentry, and therefore does not have safety criteria that apply to these personnel. It is important to know the definitions of each of these categories so that population centers are categorized appropriately. The population model should identify the appropriate category for each population center. A region may have more than one population center if there are people in different categories at the same location. The acceptable risk to NOP in §§ 450.101(a)(1)(ii) and 450.101(b)(1)(ii) is twice that of the rest of the general public in §§ 450.101(a)(1)(i) and 450.101(b)(1)(i).

7.3.1 Personnel Involved in Supporting a Launch or Reentry.

Personnel involved in supporting a launch or reentry do not meet the definition of "public" in § 401.7. These personnel may include individuals providing goods or services related to launch or reentry processing or to flight, and those ensuring safety, such as safety inspectors or security guards who are preventing people from entering flight hazard areas. Employees of vehicle operator licensee or launch or reentry site licensee may be designated as being involved in supporting a launch or reentry if they provide goods or services related to the launch or reentry processing or flight. Likewise, employees of contractors, subcontractors, payload operators, or government personnel may be involved in supporting a launch or reentry. Visitors not involved in supporting the launch or reentry, and individuals providing goods or services not related to launch or reentry processing or flight are considered public, per the definition in § 401.7.
No one who is a guest without a necessary function in the operation, nor any visitors or individuals providing goods or services not related to launch or reentry processing or flight should be designated as operational support. An operator should ensure that the numbers used in any population model are accurate and that personnel involved in supporting a launch or reentry are not counted as public.

7.3.2 Neighboring Operations Personnel (NOP).

Per § 401.7, NOP means those members of the public located within a launch or reentry site, or an adjacent launch or reentry site, who are not associated with a specific hazardous licensed or permitted operation currently being conducted, but are required to perform safety, security, or critical tasks at the site and are notified of the operation. While still considered members of the public, NOP are subjected to different individual and E_C risk criteria. Per § 450.101(a)(1)(ii) and (b)(1)(ii), the collective exposure to risk for NOP must not exceed an expected number of 2×10^{-4} casualties, and per § 450.101(a)(2)(ii) and (b)(2)(ii) the risk to any individual categorized as NOP must not exceed a probability of casualty of 1×10^{-5} per launch. The NOP definition's reference to safety, security, or critical tasks is intended to maintain flexibility to include various tasks as industry practices evolve over time. These tasks may include maintaining the security of a site or facility or performing critical launch processing tasks such as monitoring pressure vessels or testing safety-critical systems of a launch vehicle for an upcoming mission. These tasks may also include business operations that cannot be reasonably conducted off site, such as onsite hardware work as well as data processing that must be conducted in a secure facility.

Note: Personnel who are not required to perform safety, security, or critical tasks at the site are not considered NOP pursuant to § 401.7. Examples of such individuals may include individuals conducting normal business operations that need not be conducted in hazardous areas, individuals in training for any job, and individuals performing routine activities such as administrative, office building maintenance, human resource functions, or janitorial work.

7.3.3 Public.

Everyone who falls under the definition of "public" in § 401.7 and who does not qualify as NOP is subject to the same collective and individual risk requirements in § 450.101. Members of the public can be anywhere, even on-facility during the launch (although the applicant may want to restrict public population movement within hazard areas; this is discussed in § 450.161, *Control of Hazard Areas*). In accordance with § 450.101(a)(1)(i) and 450.101(b)(1)(i), the collective exposure to risk must not exceed an expected number of 1×10^{-4} casualties and the risk to any individual must not exceed a probability of casualty of 1×10^{-6}. However, only members of the public in uncontrolled areas, excluding NOP, are considered in the conditional expected casualties (CE_C) calculation pursuant to § 450.101(c)(2) (see AC 450.101-1 for a discussion of which are controlled and uncontrolled areas).

8 POPULATION EXPOSURE ANALYSIS – CONSTRAINTS.

8.1 Characterize Distributions of People Geographically and Temporally.

In accordance with § 450.123(b)(1), the exposure analysis must characterize the distribution of people both geographically and temporally. The following paragraphs in this AC provide a means of compliance to characterize these distributions within the identified region(s) of interest. Resolution in space and time should be sufficient to demonstrate compliance with the safety criteria when the operation is initiated. In the context of population center fidelity, resolution in space should be defined as the geospatial area in which a population is defined, and resolution in time should be defined as the recency of the data.

8.1.1 Geographical Distributions of People.

A valid population exposure model may use different resolutions (i.e. population center sizes) for different locations. The key factor is that risk should be constant across the population center (as defined in this AC). Different resolutions of population data could occur either because the population density or the probability of casualty is sufficiently uniform across the population center. For example, the resolution of population data for an on-facility area generally should be much finer than the resolution of population data downrange, where debris impact probability distributions typically span a much larger geographical area. Figure 1 of this AC graphically illustrates the concept of matching population resolution to the size of debris impact probability dispersions (also known as footprints). A series of debris footprints within which the debris could impact are displayed along with modeled population centers of varying sizes.

8.1.1.1 The top left image in figure 1 of this AC shows population centers that are too large as compared to the debris impact probability dispersions. If the resolution of the population centers is this large relative to the debris dispersions, then it can lead to inaccurate risk results. However, if population centers can be adequately modeled with uniform distributions of buildings and population, then larger population centers may be used without loss of precision in casualty expectation calculations.

8.1.1.2 The top right image in figure 1 shows populations that are too small as compared to the debris dispersions. While this will allow for accurately calculated risk, using this resolution everywhere might not be computationally feasible.

8.1.1.3 The bottom two images in figure 1 show appropriately sized population centers.

8.1.1.4 To demonstrate compliance with the safety criteria, an adequate risk assessment should resolve debris impact dispersions so that the impact probability contours are smooth and continuous, in accordance with § 450.119(b). Multiple overlapping fragment groups will result in smoother probability contours. An assessment of the dimensions of the probability contours can then be used to assess the degree of refinement that should be applied. In practical applications, population center sizes are usually aggregated over groups of these high-resolution cells to arrive at a compromise between the maximum population center resolution and total number of population centers that need to be processed in risk analysis tools.

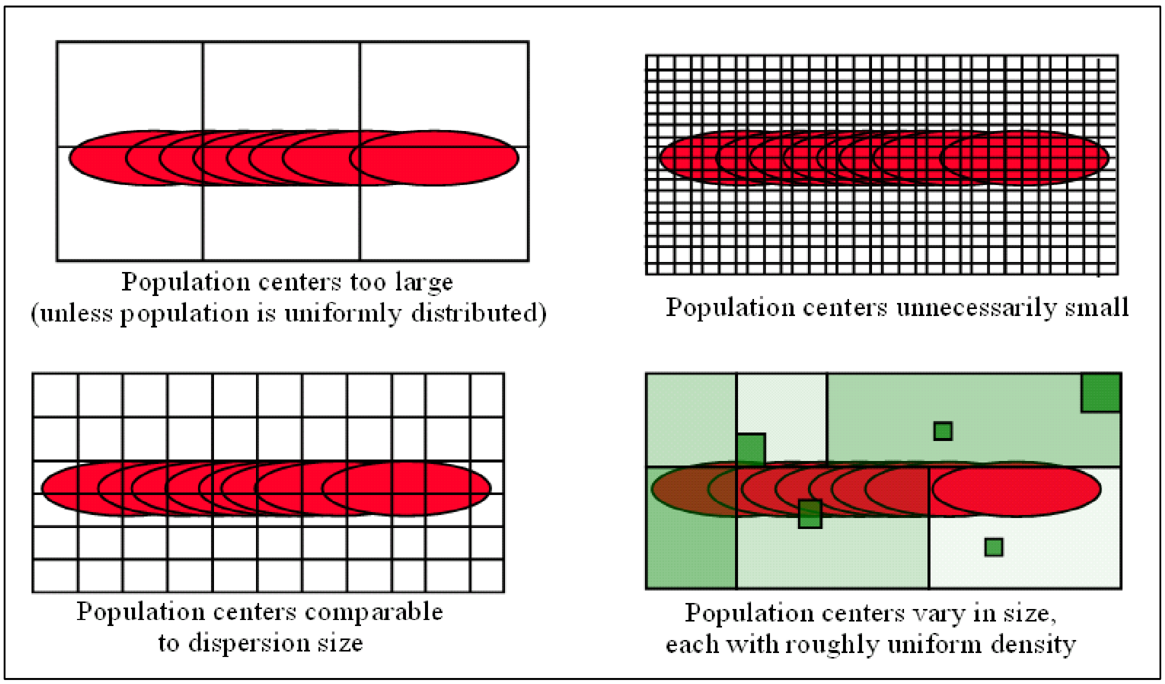

Figure 1. Population Data Resolution as a Function of Dispersion[3]

8.1.1.5 On-Facility Populations Data Resolution.

On-facility populations usually experience the highest risk during a mission. In the launch area, debris footprints typically span several hundred to more than ten thousand feet. Due to the small impact probability dispersion size, the resolution of the population data at the launch area should be by individual building.

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[3] Figure 1 of this AC is derived from Figure 4.1.37 in the following reference: Allahdadi, Firooz A., Isabelle Rongier, Tommaso Sgobba, and Paul D. Wilde, *Safety Design for Space Operations*, Sponsored by The International Association for the Advancement of Space Safety, (Watham, MA: Elsevier, 2013).

8.1.1.6 Spectators.

Some missions may have spectator areas. Due to collecting many people in one location near the mission, there is the potential for a single accident causing many casualties. This group can be the largest contribution to risk, and particularly important for the FAA's calculation of Maximum Probable Loss (MPL) determinations for financial responsibility purposes. It may be necessary to manage location and access to spectator areas to meet the safety criteria and remain consistent with the MPL determination.

8.1.1.7 Near-Facility Populations Data Resolution.

Near-facility is not precisely defined. The region where high resolution should be used depends on the size of the dispersions and the potential consequences of an accident. Generally, this region extends from the launch or reentry site boundary up to about 50 km from the flight path, where the vehicle IIP is moving slower than several km per second, but it may be smaller for smaller vehicles. As noted above, smaller dispersions could necessitate higher resolution, but the accuracy that is needed for a vehicle with small consequence can be less than for a large vehicle. The typical resolution for near-facility population sheltering data should be by small groups of buildings. This could be a city block, a housing tract, or a few square km for rural regions. Detailed population models typically include "point receptors" to account for high density population areas or other areas of special concern such as schools, hospitals, spectator areas, stadiums, cruise terminals, recreational areas (such as crowded beaches), chemical processing plants or nuclear plants, etc.

8.1.1.7.1 Grouping by Structure Class.

Although it is suggested that buildings are grouped when accounting for population, it is important to keep in mind that groups of buildings can have multiple construction types. This generalization issue can be solved by allocating people by approximate percentage to different building classes. More information about building classes can be found in paragraph 8.2.2 of this AC.

8.1.1.7.2 Accuracy.

While these population centers are larger than the on-facility centers, the accuracy of the near-facility population still should be good, as the risk to near-population centers has a significant effect on public safety. When considering near-facility populations, the applicant should ensure both "permanent" (people who live in this area and are there year-round) and "temporary" (people who are only visiting the area for vacation, business, etc.) populations are accounted for. The applicant should also consider significant areas where populations might be. This can include launch viewing areas, vacation locations (e.g. parks, beaches, and hotels), seasonal events (e.g. harvest, fishing), schools, stadiums, and airports. Applicants should also address isolated or transient structures such as oil platforms, boats, and significant roads. Time variations also should be accounted for. Daytime, nighttime, weekdays, and weekends can determine if people are at work or home, outdoors or inside. Seasons or events can determine whether to expect more or less people in the area. Given a known launch is occurring, an operator should account for people congregating outside (homes and office buildings), observing from rooftops, and pulling to the side of roads. More information about temporal variation can be found in paragraph 8.1.2 of this AC.

8.1.1.7.3 Example of Population Center near a Launch Site.

Figure 2 shows an example of the resolution of regional population centers near a launch site. The purple circle shows where the launch pads are. Within about 5 km of the launch site, individual buildings are specified. A higher resolution is also used in an area north of the launch pads because part of the base exists in that area. Out to about a 15 km radius from the launch site, 1 km cells are used.

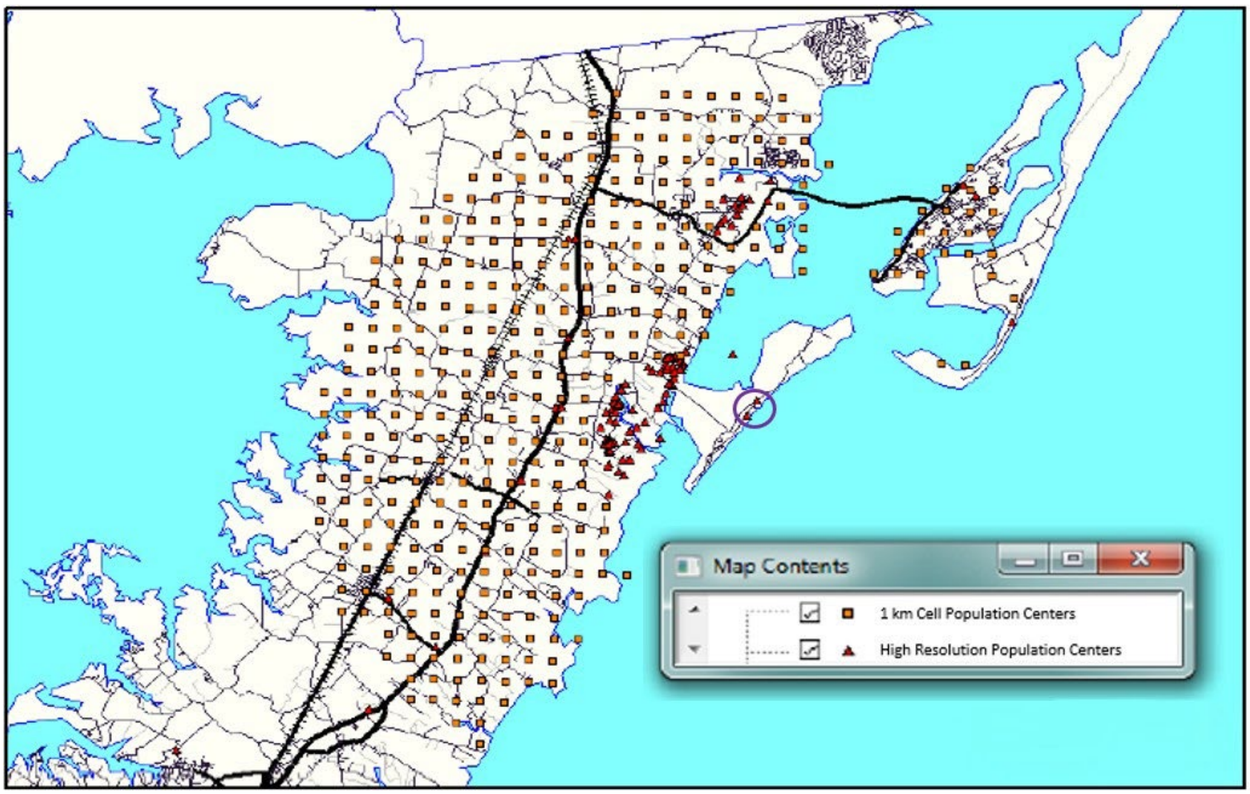

Figure 2. Near Facility Population Data Example

8.1.1.8 Downrange Populations Data Resolution.

Population centers that are far downrange from the launch site are typically defined in terms of population density and structure types within latitude-longitude grid cells. Densely populated urban centers located far downrange should be treated as separate population centers and their population count deducted from the latitude – longitude cell(s) that contain the urban center. In a lower fidelity population exposure model, counties, states, or even countries with average population densities and demographically linked structure types might be used. However, when applying lower fidelity modeling assumptions, the effect of uncertainty in the population density and structure definitions on risk and hazard area predictions should be evaluated in accordance with § 450.115(b).

8.1.1.8.1 Extent and Resolution.

The population model should encompass the area that includes all foreseeable impact locations resulting from all credible failure modes. In situations where the land area subject to potential debris impacts is large and the population at risk generally dispersed, such that population distribution is uniform, a simple population model may be based on a database of cells defined by a grid covering the hazarded land area.
A latitude-longitude grid system is commonly used where each grid cell covers an area defined by ranges of latitude and longitude. The location of a cell should be defined in terms of the coordinates (usually latitude and longitude) of the centroid of the populated area. The area of the population center is the land area of the cell and this value is used in the probability of impact calculations for debris dispersions that fall on the cell. For each cell, the number of people and sheltering distribution should be specified over the time period subject to debris impacts. Population is then assumed to be uniformly distributed within each cell, and cell sizes should be selected to provide adequate resolution as discussed below. The area under the flight path should be higher resolution than areas further away from the flight path.

8.1.1.8.2 Example of Downrange Population Center Area.

A variable resolution should be used for downrange populations, as demonstrated in figure 3 of this AC. The red dots represent the nominal trajectory. The green and red squares underneath represent the population density. The size of the square represents the population area. The brighter the green, the smaller the population density is. Darker green and red squares indicate high population densities, as described in population density key in figure 3. The squares underneath the trajectory are smaller due to a higher resolution. Gaps can be seen between population areas. These are areas where either no people or an extremely limited number of people are located.

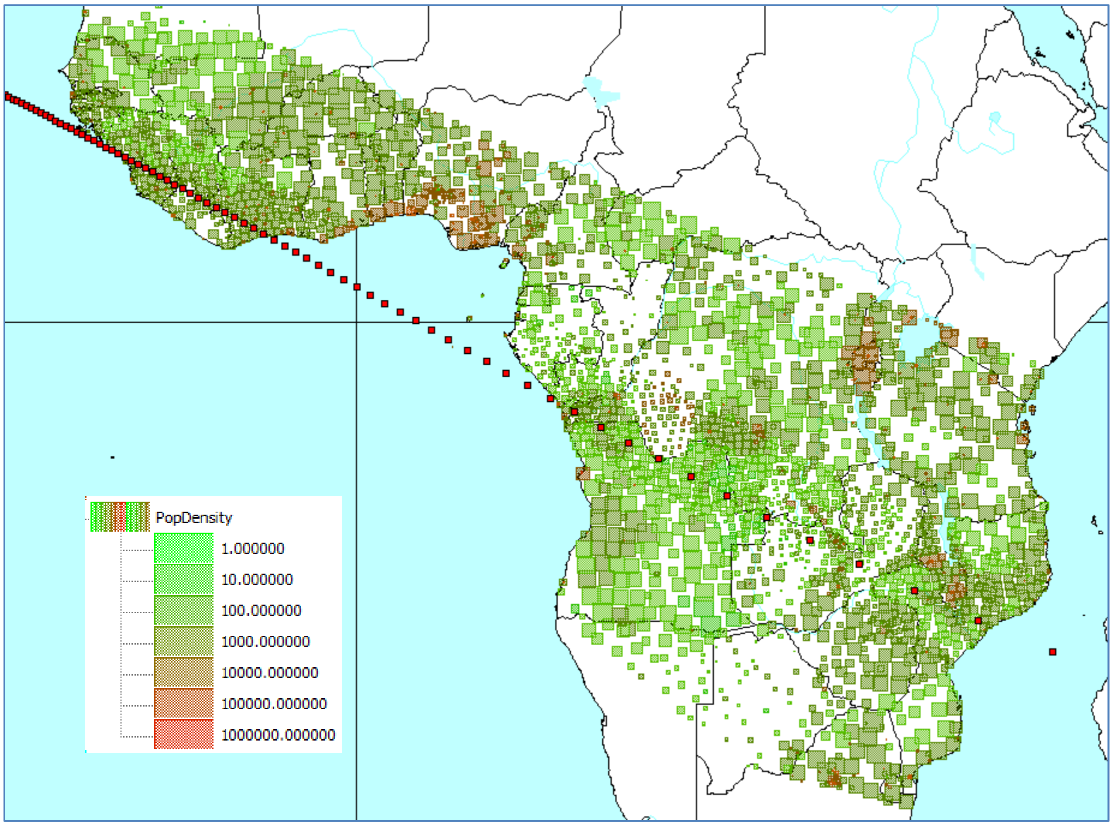

Figure 3. Example of Downrange Population Center Areas

8.1.2 <u>Temporal Distributions of People</u>.

Section 450.123(b)(1) requires that the analysis must characterize the distribution of people temporally. People move between locations and structure classes for many different reasons, on timescales from daily (e.g. work vs. home) to annual (e.g. vacationers). In addition, specific events, such as cruise ship sailings, can have a significant effect, and weather also affects the choice of activity. Sheltering and geographic location should be accounted for via multiple population exposure data sets as appropriate to support launch and reentry missions.

8.1.2.1 Movement Based on Time of Day, Day of Week, and Seasons.

The day vs. night movement is typically the most significant effect, as this changes both location and sheltering of people. People often move around significantly throughout the day due to events. For on-facility populations, the activities happening during time of launch will determine where people may be located. Off-base, people may be commuting based on time of day. The location to which they are commuting can also depend on time of day, or day of week. Customers may be eating indoors or outdoors at restaurants depending on time of day, day of week, and weather. Hotels and resorts can have different populations based on time of day and year. Beaches and campgrounds can have different populations based on time of day, day of week, and weather. At ports, ships can be loading and unloading, which is another influx of people. Likewise, airports are also generating a large rush of people coming and going. Mission times in locations around launch areas can also affect population movement as usually large open areas with high visibility can attract spectators. High-interest launches can generate an extremely large spectator population, as opposed to an "ordinary" launch which may only attract a few hundred spectators. Seasonal factors can affect the number of students at schools, the number of agricultural workers in fields or gatherings at tourist sites.

8.1.2.2 Near-Facility Populations.

For near-facility populations where the resolution is relatively high, applicants should account for areas where people may be gathered, such as beaches, campsites, and parks. The populations in these areas will fluctuate with time, so applicants should obtain data on the number of people in these areas per month. Table 1 of this AC shows an example of data collected for the number of people that are typically at beaches near a launch site. The data collected considers seasons, day of week, time of day, and weather.

Table 1. Data Collected for Beaches near Launch Site

Location	Description	Maximum	Weekend In-Season	Weekend Off-Season	Weekday In-Season	Weekday Off-Season	Night / Rain
Beach 1	Outside	2500	1400	600	400	200	10
Concessions	Outside	40	20	20	10	5	2
Concessions	Inside	40	40	40	20	10	0
Beach 2	Outside	400	280	120	80	40	2
Beach 3	Outside	600	420	180	120	60	4

Note: The units in the above table refers to the total number of people at these locations at these times.

8.1.2.3 Foreign Countries.

For missions that affect foreign countries, applicants should consider how temporal distributions can differ from the United States. Different countries can have different work hours and work weeks. For example, some countries in the Middle East have work weeks that last from Saturday to Thursday, or Sunday to Thursday. In the case of Saturday to Thursday, there is only a one-day weekend, which is Friday. In some countries, like India or Japan, there may be many companies where employees have workdays that last more than eight hours.

8.2 **Sheltering.**

According to § 450.123(b)(2), the exposure analysis must account for the distribution of people among structures and vehicle types. This is commonly referred to as "sheltering." The key purpose of sheltering modeling is assigning each population center parameters that quantitatively link to the vulnerability modeling in the debris, far-field blast overpressure (FFBO), and/or toxic risk analyses. These parameters should characterize the structure(s) such that the accuracy of the risk metrics is sufficient to demonstrate compliance with the safety criteria when the operation is initiated.

8.2.1 Important Factors.

For most debris, a structure provides protection to people inside. However, for some debris, people in structures are more vulnerable than people outdoors.

8.2.1.1 Buildings.

The roof of a building provides protection from the most common hazard: small inert debris. However, people in a weak building or a building with windows are typically more vulnerable to serious injury from a nearby explosion or FFBO event than those outdoors. Also, inert impacts of larger fragments can cause partial or full roof collapse, or other damage to a building, resulting in a larger casualty area than if the occupants were not sheltered. The ventilation system can also affect the likelihood of casualty due to toxics.

8.2.1.2 Vehicles.

Vehicles are of particular interest for two reasons. First, the motion can add to the velocity at impact, leading to a higher kinetic energy than just from the debris. Second, a driver could be affected by the hazard, and the driver's response could lead to a casualty.

8.2.1.3 Waterborne Vessels.

Waterborne vessels pose a special challenge as there are many scenarios where everyone on board is affected. This is especially important for vessels out of reach of emergency response or where the survival time of people in the water is short (due to temperature or sea state). Debris can also puncture the deck and either ignite fuel (especially for tankers) or penetrate the hull. Large inert debris might miss the vessel but cause a surface wave due to displacement, which can cause injuries. Likewise, nearby explosions can cause effects due to the shockwave travelling underwater, which transmits energy far more efficiently to the vessel than does the air shock. The properties of the vessel are very important to these vulnerabilities, especially as vessels range from very small (and vulnerable) private boats to large cruise ships (very strong, but extremely high density of people) to super-tankers (which can be transporting flammable material).

8.2.2 Characterizing Buildings.

Depending on the type of hazard, sheltering categories may be different. For explosive debris, the wall type and window parameters should be characterized. For inert debris, the roof type and number of floors should be characterized. Typically, inert debris will not penetrate more than two floors beneath the roof. For toxic hazards, the potential for ingress of toxic materials is dependent on the air exchange rate provided by construction type, e.g., whether a building is leaky or tight. All building types may be conservatively assumed to be leaky. If the risk thresholds cannot be met with that conservative assumption, then the permeability of the buildings should be accounted for. For overpressure blast effects, window type, size, and amount are important. Therefore, a comprehensive sheltering model should characterize a building type by roofing material (e.g., wood/tile, steel), overall construction type (e.g., reinforced concrete, wood frame), and window types (e.g., annealed, dual pane, tempered) and sizes.

8.2.2.1 Example categories.

The number of sheltering categories depends on the level of fidelity of consequence modeling employed. A simple population model may allocate people to a few sheltering categories, which may be acceptable if the casualty models for people in structures lead to conservative risks results. Table 2 of this AC gives examples of different building classes when considering inert debris. In this case, roof material is important. Table 3 gives examples of different building classes when considering explosive debris. For explosive debris, window size, frame type, and wall type are important factors to consider. Paragraph 8.2.6 gives guidance on how to assign these structure types to population data.

Table 2. Building Classes for Inert Debris

Name	Building Description
Open	Exposed people without benefit of an overhead roof
Steel	Steel frame construction with metal roof panels
Concrete	Reinforced concrete frame with concrete on steel roof and floor
Wood	Wood frame with wood roof and floors
Light-Metal	Roof of pre-engineered metal building (PEMB) or vehicle
Composite	Layered roof made up of lightweight, non-metallic materials
Weak Concrete	Poor quality concrete frame, roof, and floor Usually found in less-developed areas of the world
Tile-Roof	Wood frame, tile roof, wood floors
Weak Frame	Thin/weak wood frame, very thin roof surface (corrugated metal, thin thatch). Found in poorly-developed areas of the world

Table 3. Building Classes for Explosive Debris

Building Name	Wall Type	Frame Type	Window Size
Open	None	None	None
Small Metal	Pre-Engineered Metal	Light Steel Columns & Beams	Small
Small Wood	Small Wood	Wood Stud	Small
Med Wood	Med Wood	Wood Stud	Medium
Small Unreinforced Block	Small Unreinforced Block	Brick Shear wall	Medium
Medium/Large Unreinforced Block	Unreinforced Block	Shear Wall or Reinforced Concrete Frame	Medium
Reinforced Block	Reinforced Block	Shear Wall or Reinforced Concrete Frame	Medium
Small Reinforced Concrete	Reinforced Concrete	Reinforced Concrete Frame	Medium
Vehicle	Pre-Engineered Metal	None	Small
Trailers/Recreation Vehicles	Pre-Engineered Metal	Wood Stud	Small

8.2.3 Characterizing Motor Vehicles.

Motor vehicles (cars, buses, trucks, etc.) have fairly consistent parameters, except for size. They usually have flat sheet metal roofs that are approximately 0.04-0.05 inches thick. The sides have inner and outer metal panels. The front windshield is made of laminated glass, while the back and side windows are usually tempered glass. The vehicle speed should also be accounted for in both the impact kinetic energy, impact angle, and the projected area (an analog to "running in the rain"). For debris analyses, inert debris can puncture the roof or break the windows. Explosive debris can break windows, or in severe cases, cause the vehicle to become overturned. For toxic analyses, the analyst should assume this structure is leaky. For blast analyses, the likely failure modes are window breakage and collapse of the roof. In severe blast cases, the vehicle can become overturned.

8.2.4 Characterizing Waterborne Vessels.

When considering effects of sheltering for waterborne vessels, applicants should account for the differences between ground vehicles and waterborne vessels. If a waterborne vessel is hit and sinks, all people onboard the vessel are in danger of a casualty or fatality, no matter if they are sheltering or not. Applicants should also consider the variety of waterborne vessels that may be present in the area during launch (from cruise ships to fishing boats and varieties in between). This will determine the structure and material of the waterborne vessel. Small fishing boats can be made of wood, while larger fishing boats can be made of steel. Larger waterborne vessels are usually made of steel. Inert debris can hit people standing on deck of the waterborne vessel. The RCC 321-20 Supplement[4] provides acceptable vulnerability models for people in various types of waterborne vessels.

8.2.5 Characterizing Other Vehicles.

In certain situations, people in other vehicles, such as trains, can be at risk. These should be characterized adequately for risk modeling.

8.2.6 Characterizing Structures for Building-by-Building Modeling.

For on-facility populations, the resolution for structures should be defined per single entity or building. However, there are some cases where the population model should divide a building into sections. These cases include:

1. When the construction characteristics change significantly from one section of a building to another (e.g. part of the building has reinforced block walls while another part is a light metal construction);
2. For different floors of a building (typically for multi-floor buildings, only the first few floors from the top of the building experience significant risk; all other floors below can be categorized the same);

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[4] Risk Committee, Range Safety Group, Range Commanders Council, *Common Risk Criteria for National Test Ranges*, RCC 321-10, White Sands, NM 2010.

3. When window types, sizes, and amounts vary significantly from one section of the building to another; or
4. When the geometry changes significantly from one section of the building to another (e.g. an L-shaped building).

Note: The applicant should also consider when using the collected data to allocate some percentage of the people to be outside the building or in vehicles next to the building. Usually this is between 1 and 10 percent, depending on the building usage and time of day, but people may go outside to watch a mission.

8.2.7 Characterizing Sheltering in Near-facility Areas.

For near-facility populations, the resolution for structures should be defined by groups of buildings. Groupings include housing tracts, business parks, shopping areas (can include gas stations, restaurants, stores), and recreation areas. Within these groups, the applicant should designate what percentage is a certain building type (e.g. what percentage are single family homes. Structures with high population density, such as hospitals, schools and hotels, should be specifically categorized similar to how on-facility buildings are.

8.2.8 Characterizing Sheltering in Larger Regions.

For larger regions, demographic data should be used to determine sheltering categories. Examples on how to generalize building structures by these categories with data available can be found in paragraph 8.2.6 of this AC. AIAA Report #2005-6322[5] provides a discussion of how to use demographic data to estimate sheltering. The following is an extremely simplified example of how to calculate sheltering percentages. One population center has a population where all people are working. There are two occupation categories: office workers (assume 60 percent) and agricultural workers (assume 40 percent). Assume the office workers are always inside. The buildings they occupy could either be light (e.g. wood), medium (e.g. steel), or heavy (e.g. concrete) sheltering, with an equal probability assumption (about 33 percent each sheltering type). Note that a typical analysis would normally have many more structure categories. Assume the agricultural workers are only inside 25 percent of the time, and when they are inside, they are in light structures. The sheltering distribution can be calculated by the following equation:

[5] Larson, Erik, *Large Region Population Sheltering Models for Space Debris Risk Analysis,* American Institute of Aeronautics and Astronautics (AIAA) Atmospheric Flight Mechanics Conference and Exhibit, Report #2005-6322, San Francisco, CA, August 2005.

$$\begin{pmatrix} c_{wood} \\ c_{conrete} \\ c_{steel} \\ c_{open} \end{pmatrix} = \begin{pmatrix} 100\% \\ at\ work \end{pmatrix} \left\langle \begin{array}{r|ll} & Office & Agricultural \\ Wood & 33\% & 25\% \\ Concrete & 33\% & 0\% \\ Steel & 33\% & 0\% \\ Open & 0\% & 75\% \end{array} \right\rangle \begin{pmatrix} 60\%\ office \\ 40\%\ agricultural \end{pmatrix}$$

This equation results in:

$c_{wood} = 100\% \times (33\% \times 60\% \times 25\% \times 40\%) = 30\%$ of the population in wood structures,

$c_{concrete} = 100\% \times (33\% \times 60\% \times 0\% \times 40\%) = 20\%$ of the population in concrete structures,

$c_{steel} = 100\% \times (33\% \times 60\% \times 0\% \times 40\%) = 20\%$ of the population in steel structures,

$c_{open} = 100\% \times (33\% \times 60\% \times 75\% \times 40\%) = 30\%$ of the population in the open.

Actual calculations by the applicant will be much more complex, with more population and structure categories.

8.3 Input Data Sources.

Section 450.123(b)(3) requires applicants to use reliable, accurate, and timely source data. Reliable source data means good quality data that can be trusted. In some parts of the world, some of what is considered “official” data is inaccurate due to either poor data collection or intentional deception. Accurate source data means data that is of sufficient or appropriate resolution. Sufficient resolution is discussed in paragraph 8.1.1 of this AC. Timely source data means data that is relatively up-to-date. Data sources are only updated periodically. For example, the U.S. census is only updated every 10 years. It is important that the applicant adjusts the data they are using for the correct time period. It is possible that no single data source will have all of these qualities. Applicants may need to use multiple input data sources or make adjustments to the data to satisfy the three requirements in § 450.123(b)(3).

8.3.1 Site Operator Data.

Operators should not presume that a launch or reentry site or Federal site will provide population data, either for the facility or for the near area. If an operator desires this data, that may be accomplished via an agreement between the operator and the site. An agreement with a Federal site might not provide population data to the launch operator, but rather the Federal site may conduct the analysis as part of range safety services provided to the launch operator. Manual surveys of individual buildings may be performed to collect population and structure information for facilities on site or within a few km of the site boundary.

8.3.2 Completeness of Databases.

To comply with § 450.123(b)(3), several products (databases and software applications) are publicly available to assist in the development of a population model for risk analysis. Note that these products may be insufficient for identifying populations at specific locations (e.g. restaurants, viewing sites, etc.), particularly on launch or reentry day/night/weekend/time-of-day/etc., and may not communicate proprietary or security information (e.g. the number of people in a building at a military facility, in a company's processing facility during a work shift, etc.). These populations and buildings may be some of the closest to the hazard, thus critical to the risk assessment, and may need to be individually surveyed to provide the level of fidelity required to meet § 450.115(b).

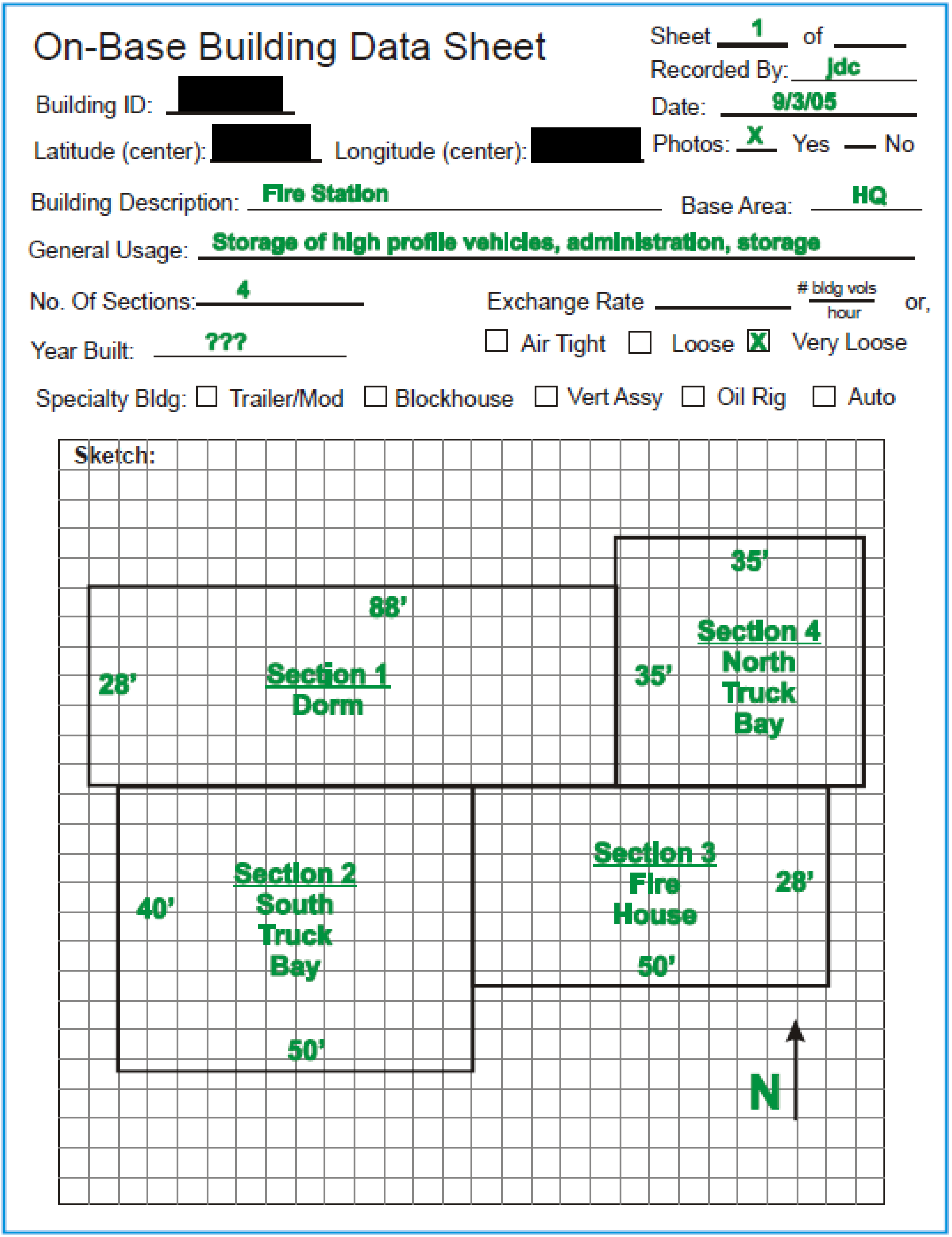
8.3.3 On-Facility Data.

On-facility population data resolution should be very high, and thus this data is usually obtained by surveying the area, if safety and security allow. When surveying on-facility populations, there should be two main focuses: building parameters, and number of people vs. time and classification (per paragraph 8.3.3.2 of this AC). The data should be validated to ensure every building has been captured. This may be accomplished by overlaying the buildings on satellite imagery, such as in Google Earth. There may be cases where an on-facility survey is not possible (e.g., for security reasons). In cases like this, the facility operator should perform the survey and provide the data to the applicant.

8.3.3.1 Building parameters.

Applicants should record the construction characteristics (e.g. frame, roof, windows, etc.), geographical coordinates, and area of the building. It may be helpful during the survey to draw or take pictures of the buildings. Building data should be recorded by floor, if possible. Examples of surveys done for a building, a section of a building, and a floor within the building can be seen in Figure 4, Figure 5, and Figure 6 of this AC. This example shows a survey of an on-base fire station. The fire station, while all one building, is broken down into different sections. Figure 4 recognizes that the building is "Very Loose" in terms of air exchange rate, indicating that a toxic exposure would infiltrate the building quickly. Figure 5 focuses on a single section of the building. It notes what the section of the building is used for, which helps with estimates of how many people will be in this section of the building during certain time periods. The surveyor also noted which side of the section that windows were on. A high-fidelity population model should go a step further and record the number and dimensions of the windows. Figure 5 also notes how many floors the section has. Figure 6 records the wall type, roof type, and frame type of the specific building section.

Figure 4. Survey Example for Building Data Sheet



On-Base Building Data Sheet

Sheet 1 of ____

Recorded By: jdc

Building ID: [redacted]

Date: 9/3/05

Latitude (center): [redacted] Longitude (center): [redacted]

Photos: X Yes — No

Building Description: Fire Station

Base Area: HQ

General Usage: Storage of high profile vehicles, administration, storage

No. Of Sections: 4

Exchange Rate ____ # bldg vols / hour or,

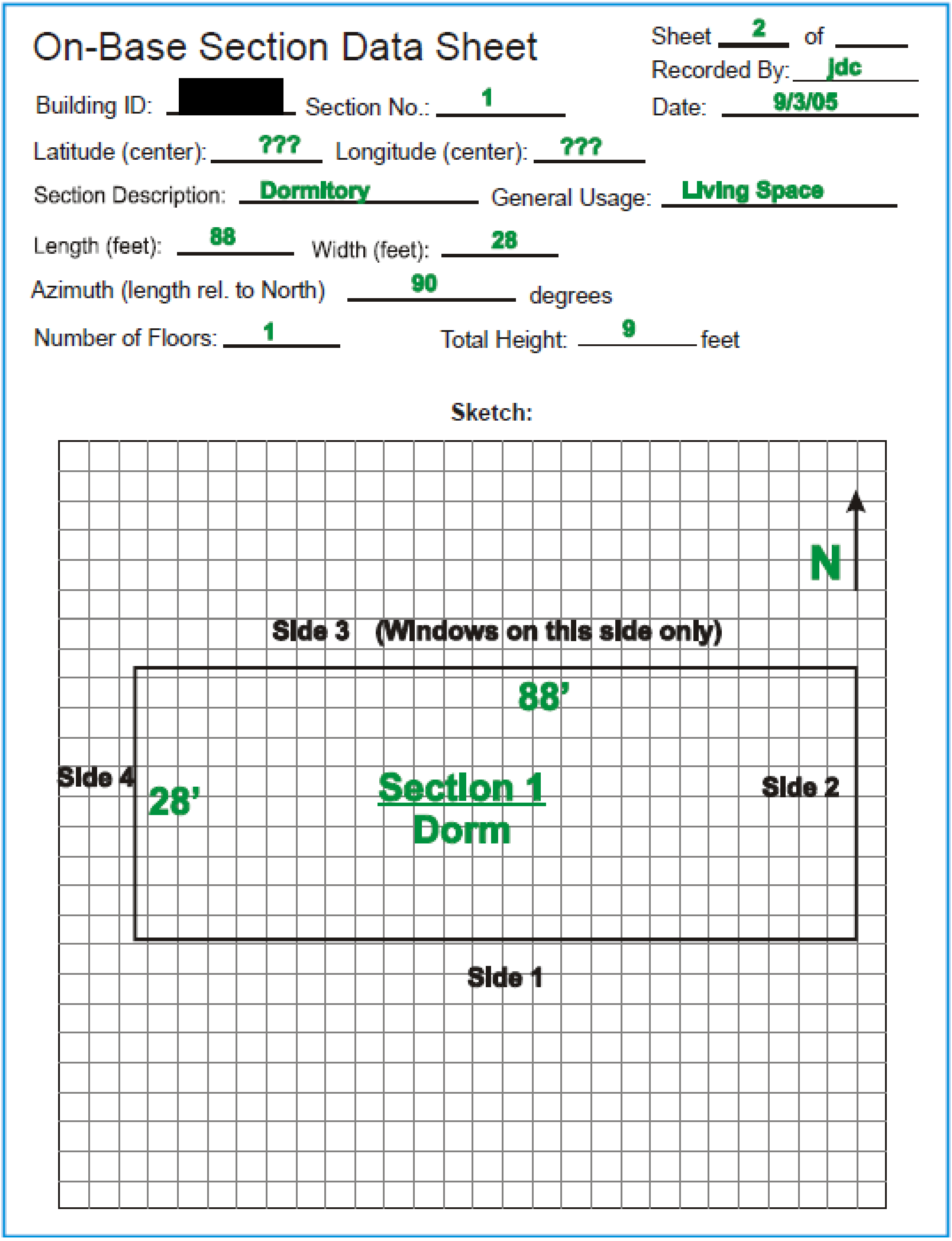
Year Built: ???

☐ Air Tight ☐ Loose ☒ Very Loose

Specialty Bldg: ☐ Trailer/Mod ☐ Blockhouse ☐ Vert Assy ☐ Oil Rig ☐ Auto

Sketch:

Figure 5. Survey Example for Section Data Sheet



On-Base Section Data Sheet

Sheet 2 of ____

Recorded By: jdc

Building ID: [redacted] Section No.: 1

Date: 9/3/05

Latitude (center): ??? Longitude (center): ???

Section Description: Dormitory General Usage: Living Space

Length (feet): 88 Width (feet): 28

Azimuth (length rel. to North) 90 degrees

Number of Floors: 1 Total Height: 9 feet

Sketch:

Figure 6. Survey Example for Floor Data Sheet

On-Base Floor Data Sheet

Sheet 3 of ____

Recorded By: jdc

Building ID: [redacted] Sect No.: 1 Floor No.: 1 Date: 9/3/05

Description: Dormitory Organization: [redacted]

Height: 9 feet

Wall Type

1) ____ Wood Stud
2) ____ Metal Stud
3) ____ Unreinf Brick
4) X Unreinf Block
5) ____ Reinf Block
6) ____ Light Metal
7) ____ Heavy Metal
8) ____ Reinforced Concrete
9) ____ RC Tiltup
10) ____ Unknown

Floor/Roof Type

1) X Builtup/Composite
2) ____ Light Wood
3) ____ Wood Panelized
4) ____ Lt-Wt Metal Deck on Stl Joist
5) ____ Lt-Wt Conc on Metal Deck
6) ____ Heavy Metal on Stl Girder
7) ____ Reinf Conc on Metal Deck
8) ____ Reinforced Concrete
9) ____ Tile
10) ____ Unknown

Frame Type

1) ____ Wood Stud (bearing wall)
2) ____ Metal Stud (bearing wall)
3) ____ Steel Braced
4) ____ Steel Moment Resisting
5) X Concrete Moment Resisting
6) ____ Unknown

8.3.3.2 Number of People.

The second focus or survey is number of people. This may be done by a physical counting of occupants in the building at different times of the day. If this is not possible, the applicant should obtain the information from the facility operator. It is important, during the survey, to also get an idea of the variability of the on-facility population with time. The survey should specify when people are in the building during daytime, nighttime, weekdays, or weekends. More temporal variation data to consider recording during the survey is discussed in paragraph 8.1.2 of this AC. The people also should be categorized as personnel involved in supporting a launch or reentry, NOP, or other public, and whether they are government personnel (for MPL considerations). When collecting data for NOP, applicants either should be conservative or work with site operators to get up-to-date data on what NOP will be in the area during the operation. More specifically, the launch or reentry operator should work with the site operator (i.e., an operator of a Federal site or FAA-licensed launch or reentry site) and the operators of any neighboring sites to identify NOP personnel because the site operators are in the best position to identify which personnel are required to perform safety, security, or critical tasks at the launch site.

8.3.4 Spectator Areas.

To account for spectators, the applicant should determine where the designated spectator areas will be. The applicant may set their own spectator areas by working with the city or may work with the launch site to establish where spectators historically gather such as beaches, piers, or roadblocks. Due to the uncertainty of how many spectators could be in the area at the time, the applicant should consider calculating E_C for different varying numbers of people in the area. Table 4 shows an example of the different population sizes.

Table 4. Example of E_C for Varying Population Sizes in a Viewing Area

People in Viewing Area	Collective Risk (E_C) per million
10,000	3
30,000	7
100,000	22

8.3.5 Near-Facility Population Data.

Near-facility population data does not have the same high resolution as on-facility population data. The methods to collect this data may include a mix of surveying and database use, depending on the distance from the launch or landing site (see paragraph 8.1.1.3 of this AC for more information on resolutions for near-facility populations). At near distances all individual buildings and locations where people gather should be identified. At mid-range distances, the applicant should identify critical population centers, such as schools and hospitals, as individual buildings, but lower density population areas may represent groups of buildings (e.g. 1 km^2). At further distances, the size of lower density regions may be larger and clusters of buildings with higher density population may be used (e.g. a whole school campus).

8.3.5.1 General Data Sources.

Data may be collected by identifying structures using satellite imagery and tax assessor data. For specific buildings such as schools and hospitals, the applicant may need to survey the specific structures and contact building operators for occupancy data to provide the level of fidelity required to meet § 450.115(b). Sources for demographic data for the more generalized populations can be found in paragraph 8.3.5.2 of this AC. The LandScan USA product is very helpful for obtaining high-resolution day/night population data averages, although higher-fidelity temporal variation is not included.

8.3.5.2 Seasonal Variations.

Seasonal variations can be important factors that either alter distribution of people indoors or outdoors (e.g. more people outdoors in summer than winter) or alter total local population count (e.g. Chincoteague Island near the National Aeronautics and Space Administration (NASA) Wallops Flight Facility range has about 3,000 residents during off season winter months and 25,000 to 40,000 total population during the June-August tourist season with many of these people outdoors during the day and in local hotels at night).

8.3.5.3 Transportation Data.

Transportation modes should receive special consideration. Most public roads are not a significant contributor risk as compared to background populations, except in extremely sparely populated areas. A major road, such as a freeway, should be accounted for. Road usage information can be acquired from state Departments of Transportation and from the U.S. Bureau of Transportation.[6] Most stated transportation departments will provide the volume of cars on a road for a particular day or time period (an example of this is shown in Figure 7 of this AC). Maritime traffic information can be acquired from the Department of Transportation SeaVision.[7]

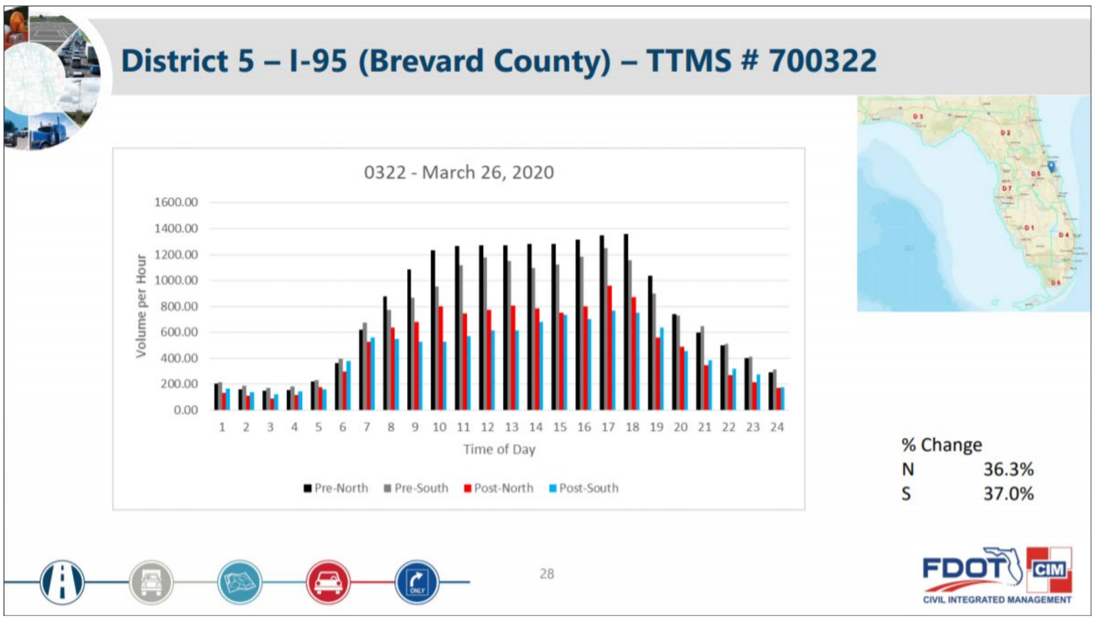


Figure 7. Example Vehicle Volume per Hour data for Brevard County for March 26, 2020[8]

8.3.6 Offshore Oil Rigs Population.

For certain sites, applicants should account for offshore oil rig populations. The population data for these sites may or may not be in a population database. Surveying these areas for population data may not be feasible. Instead, online gas and oil platform maps may be used to locate current locations around the launch site. A variety of

[6] Bureau of Transportation Statistics, "Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances", https://www.bts.gov/content/number-us-aircraft-vehicles-vessels-and-other-conveyances, 2021.

[7] https://info.seavision.volpe.dot.gov/

8 Larson, Erik, Large Region Population Sheltering Models for Space Debris Risk Analysis, American Institute of Aeronautics and Astronautics (AIAA) Atmospheric Flight Mechanics Conference and Exhibit, Report #2005-6322, San Francisco, CA, August 2005.

open-source trackers exist for location of these structures; however, official data for U.S. launches are typically provided by the Bureau of Ocean Energy Management[9] and the National Oceanic and Atmospheric Administration.[10] Applicants should conduct a survey of these resources and contact the management of potentially exposed structures for up-to-date population data.

8.3.7 Large-Region Population Data.

For regions further from the operation launch or landing site, the population data do not need as high resolution as on-facility or near-facility data. Existing datasets are typically used to develop this data, as discussed in AIAA Report #2005-6322.[4]

8.3.7.1 Use of Demographic Data.

Useful products should be divided into two groups: (1) datasets consisting of spatial data to be integrated into a model, and (2) processing and display applications used to integrate and analyze datasets. Regarding the first category, overhead imagery, state, and/or local development records, including planning and building department and U.S. Census data,[11] are often useful sources of population modeling data, including sheltering data. U.S. Census data specifies where people live and may be a source of demographic data, used to infer the distribution of people among various types of buildings. Local development records, such as a county tax assessor, may provide useful information on types of commercial buildings and zoning classification for different areas. Operators may use demographic data to assign population distributions to different classes of population groups (e.g., farmers, white-collar workers, and children) and as a function of time-of-day (workday/evening/weekend).

8.3.7.2 Sources of Demographic Data.

Table 5 of this AC provides a summary of three sources of data, which are accessible and commonly used for population modeling for flight safety analysis. All the sources in Table 5 are considered reliable, accurate, and timely sources of data consistent with § 450.123(b)(3). Information is available on potential sources of the baseline data necessary to construct a population model. Landscan[12] and Gridded Population of the World (GPW)[13] may be used to provide population estimates for grid cell areas as small as 1 square km covering the populated areas of the globe.

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[9] https://www.boem.gov/oil-gas-energy/mapping-and-data
[10] https://www.ncei.noaa.gov/
[11] United States Census Bureau, "Explore Census Data", https://data.census.gov/cedsci/, 2020.
[12] Oak Ridge National Laboratory, "LandScan, Geographic Information Science and Technology", https://landscan.ornl.gov/, 2018.
[13] Socioeconomic Data and Applications Center (SEDAC), "Gridded Population of the World (GPW), v4, CIESIN, Columbia University, New York, New York, https://sedac.ciesin.columbia.edu/, 2020.

Table 5. Comparison of Data Sources for Quantifying Populations at Risk

Source of Data:	LandScan	GPW	U.S. Census
Accuracy	Very good	Good	Excellent
Resolution	Very good	Very good	Excellent
Availability	Good	Excellent	Excellent
Completeness	Global	Global	U.S. Only
Sheltering Information	None	None	Very Good

8.3.7.3 Sheltering.

The sources above will not provide direct sheltering data for populations. However, they will provide data that is applicable to sheltering.
To provide data that is applicable to sheltering, the applicant should use three categories to generalize building structures: home, work, and school.

8.3.7.4 United States (U.S) Census Data.

The U.S. Census[14] provides data that alludes to materials and protection level of the home structure, such as number of units in a structure (1, 2 to 4, 5 or more, mobile, other). A 1-unit structure corresponds to a single-family residence, which typically in the U.S. have wood or tile roofs, while "5 or more" can correspond to apartment complexes, which typically have steel or concrete roofs. While the information is not available on a tract-by-tract basis, it is available for a larger general area. Applicants may apply the percentages of the larger general area to the specific tracts of interest.

[14] United States Census Bureau, "Explore Census Data", https://data.census.gov/cedsci/, 2020.

8.3.7.4.1 Occupational Data.

The U.S. Census Bureau also provides a breakdown of the working (civilian) population by industry and occupation. These include industry categories such as manufacturing; transportation and warehousing; retail trade; professional, scientific, management, and administrative; and arts, entertainment, recreation, accommodation, and food services. Although exact building structure types cannot be determined per industry category, building standards and other potential sources may be used to generalize building structure types per industry category. Applicants should also consider occupations that may cause the workers to be outside, or "unsheltered," for a certain percentage of their time (e.g., construction workers, agricultural workers).

8.3.7.4.2 Building Height.

Applicants should account for the floor makeup of a building where there might be more than one floor. Location of people on different floors plays an important part when determining risk. The person at the top floor will experience different risk than a person five stories below them. Typically, only three floor types should be considered: the top floor, the floor beneath the top floor, and all other floors below. For simplicity, the applicant may want to just consider that all the other floors below the first two top floors will experience similar risk. To determine how many people are located on each floor, assumptions should be made. For example, the applicant may assume that a person in a four-story building has a 25 percent likelihood of being on any of the four floor levels.

8.3.7.4.3 Schools.

The U.S. Census also provides information of people enrolled in school from grades one through college. Depending on the type of school that people are enrolled in, the applicant may make engineering judgments to create building type distributions. Schools will usually have a building code they must adhere to. The building code can vary by region. It can also vary by school type (e.g. elementary schools, high schools, universities, and daycare facilities). Many schools also utilize temporary buildings or "portables," which will have a different structure type compared to a permanent building. It is possible that this code has changed over time, so the applicant should identify when the school was built to correctly categorize the structure type.

8.3.7.5 Global Data.

Outside the U.S., demographic data that is useful for sheltering is scarce. The most useful data are the fraction of people in different occupations and in school and the gross domestic product (GDP) per capita. A correlation exists between GDP per capita and the type of construction. In general, a different model for sheltering should be used in rural than urban areas. The sheltering model should also account for typical building materials in the region of the world (some regions primarily use wood, whereas others use much more concrete).

8.3.8 Process for Data Maintenance.

To meet the "timely source data" requirement of § 450.123(b)(3), an applicant should ensure that the data products are the best available and up-to-date. Many population data services offer regular updates to their products. Data should be updated as appropriate to meet the analysis accuracy required for each mission. This does not mean that all the population modeling data should be updated for every mission, especially if there are multiple missions per year. Critical information to be addressed for each mission includes launch and reentry site population, including spectators if any population growth, redistribution, and changes in sheltering.

8.3.9 On-facility and Near-facility Data.

On-facility and near-facility population data should be updated at least annually, or if any significant development occurs. Spectator data should be updated for each mission based on lessons learned and confirmed that it does not exceed the expectation in the mission countdown.

8.3.10 Large Region Data.

Large Region data should use estimated growth rates to stay current, and with full updates at least every decade. If the uncertainties associated with a growth-model approach are small relative to other sources of uncertainty in the individual and E_C computed to demonstrate compliance with § 450.101, then the current population P may be estimated from the formula, where the annual growth rate G is a percentage/100, and the exponent is the number of years between the starting population value and the current population estimate. For near-launch and reentry areas (where the dispersion of hazardous debris is smaller), the starting population input data should be re-evaluated approximately every two years, and for downrange areas every decade (e.g. following the U.S. Census).

$$P_{new} = P_{old}(1 + G)^{\Delta G}$$

Where

P_{new} = total current population

P_{old} = starting population value

G = annual growth rate of population

ΔG = number of years between the starting population value and the current population estimate

8.4 Accounting for Vulnerability of People.

In accordance with § 450.123(b)(4), the exposure analysis must account for the vulnerability of people to hazardous debris effects. To accomplish this, the exposure model should characterize the type of structure, vessel, etc., in which people are located. An applicant should use the consequence modeling found in §§ 450.135, 450.137, and 450.139 when computing risk. An applicant should refer to AC 450.137 *Distance Focusing Overpressure (DFO) Risk Analysis*, and AC 450.139-1 *Toxic Hazard Risk Analysis*.

8.5 Ensuring Documentation, Traceability, and Configuration Management.

It is critical to maintain the documentation and traceability of all data used in a population model to: (1) allow for compliance monitoring (§ 450.209); (2) preserve data in the event of a mishap (§ 450.173(d)(4)); and (3) facilitate changes or updates using additional input data (§ 450.123(b)(3)). A configuration management process should be implemented for dataset updates to ensure that analysts use the best available data. One approach used by many of the Federal sites is to organize and maintain combined population and structures data using a database software tool. This approach allows for querying of the master data set to extract population data needed for specific missions. A launch or reentry site operator would be a logical custodian of population and structural data for the on-site population and the surrounding area out to approximately 32 km around the launch site. However, this approach is not a requirement of the launch or reentry site operator. The downrange population data is more mission specific and is typically the responsibility of the launch/reentry license applicant to develop, although commercial sources are available.

9 POPULATION EXPOSURE ANALYSIS - APPLICATION REQUIREMENTS.

To satisfy the application requirements of § 450.123(c), an applicant must submit a description of the models used to develop the exposure input data in accordance with § 450.115(c), and complete population exposure data in tabular form.

9.1 Description of Methods.

Section 450.123(c)(1) requires that an applicant submit a description of the methods used to develop the exposure input data in accordance with § 450.115(c) as described in paragraph 1.2. In addition, the applicant should explain the methods used when categorizing populations. There should be a description of what resolutions were used for what areas and why. Additionally, the applicant should describe the methods and assumptions used to temporally distribute populations. Applicants should record how they determined the sheltering and describe how they characterized structures. Data sources used should be documented to include how old the data is and what the applicant did and will do to maintain the timeliness of the data, if necessary. If surveys are done, the applicant should explain what was surveyed and what information was recorded. If surveys were not done, applicants should explain how they obtained data of the on-facility and near-facility populations.

9.2 Complete Population Exposure Data.

Section 450.123(c)(2) requires that an applicant submit its complete population exposure data, in tabular form. Common file formats should be used, such as comma separated values or spreadsheet. Documentation should explain each field, including units, and the purpose of each file provided. This data should include information on both structure classes and population data.

9.2.1 Structure Classes.

The applicant should submit a list of structure classes used in the population exposure analysis. Data for each structure class should include:

- Structure class unique identifier
- Structure class description
- Size category (area)
- Glass to floor ratio
- Wall/frame type
- Roof type
- Window type

9.2.2 Population Data.

The applicant should submit a list of all population centers used in the population exposure analysis. If there are significant variations as a function of time, these different variants should be provided as well. This may instead be accomplished by providing the

FAA the software/database from which population data is obtained. Population data should include:

- Population center name
- Population center area
- Geodetic latitude and longitude of population center centroid
- Structure classes associated with the population center
- Number of people in each structure class
- Number of structures in each structure class

9.3 **Variable Population Data.**

For population centers where the population will only be known at the time of launch, such as spectator areas, the applicant should provide the expected ranges of people present. The applicant should calculate the maximum number of people allowed at each site that still meets the safety criteria of § 450.101 prior to the day of operation, accounting for all foreseeable conditions within the flight commit criteria, per § 450.135(a)(1). Alternatively, the Flight Safety Analysis must include a debris risk analysis that demonstrates compliance with safety criteria in § 450.101 during the countdown using the best available input data, including flight commit criteria and flight abort rules, in accordance with § 450.135(a)(2). The operator should ensure that the number of people present is below the number used in its analysis.

OMB Control Number: 2120-0746
(Expiration Date: 08/31/2023)

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